NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 514

THE MEASUREMENT OF THE FIELD OF VIEW FROM AIRPLANE COCKPITS

By MELVIN N. GOUGH

1935

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AERONAUTIC SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Abbreviation	Unit	Abbreviation
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of 1 kilogram	kg	weight of 1 pound	lb.
Power	P	horsepower (metric)		horsepower	hp.
Speed	V	kilometers per hour	k.p.h.	miles per hour	m.p.h.
		meters per second	m.p.s.	feet per second	f.p.s.

2. GENERAL SYMBOLS

W, Weight $= mg$

g, Standard acceleration of gravity $= 9.80665$ m/s^2 or 32.1740 ft./sec.^{2}

m, Mass $= \frac{W}{g}$

I, Moment of inertia $= mk^2$. (Indicate axis of radius of gyration k by proper subscript.)

μ, Coefficient of viscosity

ν, Kinematic viscosity

ρ, Density (mass per unit volume)

Standard density of dry air, 0.12497 kg-m^{-4}-s^2 at 15° C. and 760 mm; or 0.002378 lb.-ft.$^{-4}$ sec.^{2}

Specific weight of "standard" air, 1.2255 kg/m^3 or 0.07651 lb./cu.ft.

3. AERODYNAMIC SYMBOLS

S, Area

S_w, Area of wing

G, Gap

b, Span

c, Chord

$\frac{b^2}{S}$, Aspect ratio

V, True air speed

q, Dynamic pressure $= \frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L = \frac{L}{qS}$

D, Drag, absolute coefficient $C_D = \frac{D}{qS}$

D_o, Profile drag, absolute coefficient $C_{D_o} = \frac{D_o}{qS}$

D_i, Induced drag, absolute coefficient $C_{D_i} = \frac{D_i}{qS}$

D_p, Parasite drag, absolute coefficient $C_{D_p} = \frac{D_p}{qS}$

C, Cross-wind force, absolute coefficient $C_C = \frac{C}{qS}$

R, Resultant force

i_w, Angle of setting of wings (relative to thrust line)

i_t, Angle of stabilizer setting (relative to thrust line)

Q, Resultant moment

Ω, Resultant angular velocity

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension (e.g., for a model airfoil 3 in. chord, 100 m.p.h. normal pressure at 15° C., the corresponding number is 234,000; or for a model of 10 cm chord, 40 m.p.s. the corresponding number is 274,000)

C_p, Center-of-pressure coefficient (ratio of distance of *c.p.* from leading edge to chord length)

α, Angle of attack

ϵ, Angle of downwash

α_o, Angle of attack, infinite aspect ratio

α_i, Angle of attack, induced

α_a, Angle of attack, absolute (measured from zero-lift position)

γ, Flight-path angle

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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THE MEASUREMENT OF THE FIELD OF VIEW FROM AIRPLANE COCKPITS

By Melvin N. Gough

SUMMARY

A method has been devised for the angular measurement and graphic portrayal of the view obtained from the pilot's cockpit of an airplane. The assumptions upon which the method is based and a description of the instrument, designated a "visiometer", used in the measurements are given. Account is taken of the fact that the pilot has 2 eyes and thus 2 separate sources of vision. The view is represented on charts using an equal-area polar projection, a description and proof of which are given. The use of this chart, aside from its simplicity, may make possible the establishment of simple criterions of the field of view. Charts of five representative airplanes with various cockpit arrangements are included.

INTRODUCTION

It is becoming increasingly evident that a good field of view from the pilot's cockpit of an airplane is one of the main requirements for safe flying. The airplane has several characteristics that necessitate an unusually open field of view for the pilot. These characteristics are: relatively high speed, capability of maneuverability in three-dimensional space, and principal axes unconnected to those of other objects fixed or in motion.

Probably the first notable realization of the vital importance of a good field of view arose during the World War. Many pilots went so far as to remove the fabric from various portions of their airplanes in an attempt to eliminate "blind spots", accepting the suspected loss of performance (reference 1). The results of war time efforts to improve the angles of gunfire and reduce the vulnerable blind sectors were at the time considered military secrets (references 2, 3, and 4), but are now available to a considerable extent in literature on airplane design (references 5 and 6).

The rapid growth of commercial aviation since the war has added to the demand for a better understanding of vision requirements (references 7 and 8). Many methods of determining such requirements have been proposed and tried (references 2, 3, 9, 10, and 11). No systematic study of the problem having been made, the question of providing an adequate field of view is generally left to the judgment of the designer. Any rating of the field of view of the completed airplane would be very arbitrary and is usually confined to pilots' reports of "good" or "bad." Several attempts to establish a coefficient for rating the vision characteristics of airplanes have been unsuccessful owing to the lack of information concerning the field of view of the already existing types.

Because of the various requirements, it is desirable to know to what degree and in what direction vision is necessary for a given purpose and under various conditions of flight. It is also very desirable that a simple and exact means be made available by which the prospective operator may make known his wants and the manufacturer denote how nearly he is able to fulfill them.

The development of a simple and exact method of measuring and presenting the field of view from the pilot's cockpit should make possible a systematic collection of data from a large number of existing representative airplanes, which, together with existing ideas concerning the known usefulness of the view they afford and their suitability for the intended function, may make possible a comparative evaluation of this almost neglected quality. A study of the relative importance of various portions of the field of view should prove of value in the design of new types; the manner in which they compare with the old should become as evident to the designer as to the pilot.

The present report describes a practicable method for measuring and presenting the pilot's field of view. An instrument designated a "visiometer" was constructed that permits a step-by-step measurement of the outline of the airplane as seen by the pilot. The data thus obtained are plotted directly on a form of polar chart from which areas may be measured. Information on 36 airplanes has been satisfactorily obtained. These studies are being conducted by the National Advisory Committee for Aeronautics at Langley Field, Va.

METHOD OF MEASUREMENT

Preliminary considerations.—In the method employed the pilot of an airplane is considered to be at the center of an imaginary sphere whose radius is

infinitely larger than the distance from the pilot to any part of the airplane. The outline of the portions of the airplane seen by the pilot may then be projected onto the surface of the sphere and defined by the lengths of arcs on the spherical surface or by the angles which they subtend at the center of the sphere. At present only the forward hemisphere, symmetrical about the direction of flight, is being considered.

The location of the point to be considered as the center of the sphere is based on several assumptions, some of which follow. The height of the plane of the eyes of the average pilot is about 31 inches above the seat cushion or parachute. In a natural position a head movement of 6 inches to either side of the position of direct forward vision is easily obtainable. No fore-and-aft movement is considered here. For airplanes with adjustable seats, the seat is raised to its highest position for taking-off, landing, and taxying, and lowered during flight just to afford protection behind the windshield. These factors determine four

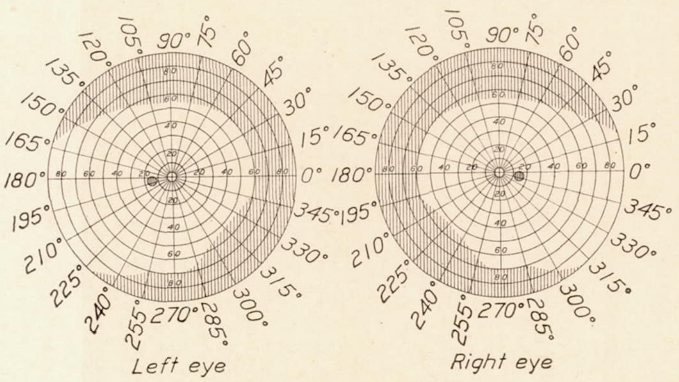


FIGURE 1.—Fields of vision of the eyes of the average pilot.

positions considered as representative of those naturally assumed by a pilot under normal conditions; namely, flight attitude, pilot central; flight attitude, pilot to one side; landing attitude, pilot central; and landing attitude, pilot to one side.

The natural position of the pilot is one of rest with face forward and head erect and with the line of sight directed forward along the line of flight. From this position the two most natural motions of the head are obtained by rotation about a lateral axis and about a vertical axis. Motion about a longitudinal axis, if made by the pilot, is usually accompanied by a lateral swaying of the body and requires considerable effort. By the two previously mentioned motions of the head the pilot may direct his sight to any point in the forward hemisphere, maintaining his line of sight normal to a line between the pupils of his eyes. For the average pilot it has been found that, with fixed body, the eyes move approximately on the surface of a sphere of 4.6 inches radius, the center of which may be assumed to be in the horizontal plane containing the eyes when the head is erect.

It is evident that the projection of the airplane from a single observation point represents the view seen with monocular vision; actually, binocular vision exists and should be considered. Although it is possible, but unnatural, for the pilot to place his head in the positions necessary to obtain the maximum benefit of binocular vision in all planes, the assumption is made, on the basis of the previously considered motions, that the line between the eyes is maintained horizontal.

It should be mentioned, although it will be given no consideration, that the pilot can move his eyes while

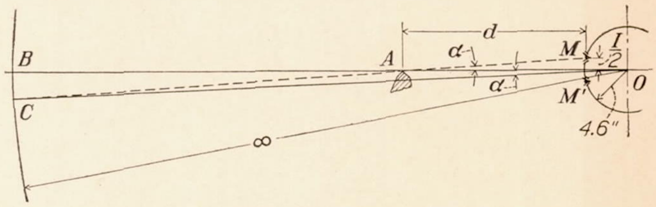


FIGURE 2.—Binocular vision in the plane of the eyes.

holding his head stationary. The pilot therefore possesses binocular vision regardless of the location of the object, provided that it is within the field of binocular fixation, which extends roughly 50° from the primary position of the eye. (See fig. 1 and reference 12.)

Physical examinations of service pilots have shown the interpupillary distance between the eyes of the average pilot to be 2.5 inches (reference 12). An obstruction of smaller dimensions than 2.5 inches may be neglected since, with binocular vision, convergence occurs beyond it and it ceases to be a blind spot. This

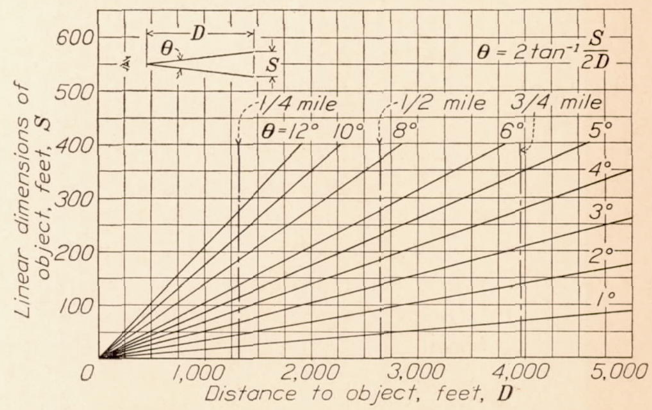


FIGURE 3.—Angles subtended by distant objects. (Interpupillary distance so small as to effect no difference between monocular and binocular vision.)

effect is a maximum in planes containing the line joining the two eyes of the pilot.

The diagram shown in figure 2 has been constructed to show the effect of binocular vision in the plane of the eyes. The two eye positions M and M' are located having an eccentricity $I/2$ with respect to monocular vision, where I is the average interpupillary distance. Monocular vision from O locates a point of object A on the sphere at point B, but sight from M locates A at C. As the sphere is considered to have an infinite radius, the line CM is parallel to the line CO and the

arc BC may be measured at the center of the sphere by the angle α.

$$\alpha = \tan^{-1}\frac{I}{2d}$$

By measurement, therefore, from a single point the positions on the surface of the imaginary sphere of the outline of the obstruction are improperly located in all planes containing the eyes by an amount equal to the angle α and the blind angle subtending the obstruction is represented as too large. The error, moreover, is wholly dependent on the distance of the obstruction from the pilot and varies inversely as d. In applying a correction for this error, particularly for obstructions of large area, one must take into account which eye is causing the blind-angle reduction and the location of the portions of the edge of the obstruction with respect to the line of sight.

It is evident that reasonably large objects may be hidden by blind angles of small magnitude (fig. 3). An object, such as another airplane, with a linear dimension of 40 feet along its longitudinal or lateral axis, subtends an angle of less than 1° at a distance of one-half mile. A dimension on the vertical axis of 15 feet subtends an angle of approximately 0.3°.

N. A. C. A. visiometer.—When considering the measurement of fields of view, one immediately thinks of the camera because of its similarity to the eye. Previous investigators have used the pinhole camera (reference 11) and have also photographed the image of the airplane on a spherical mirror. Among other things, however, the difficulty of superimposing the photographs or the possibilities of applying a correction for binocular vision resulted in favoring a step-by-step angular measurement method.

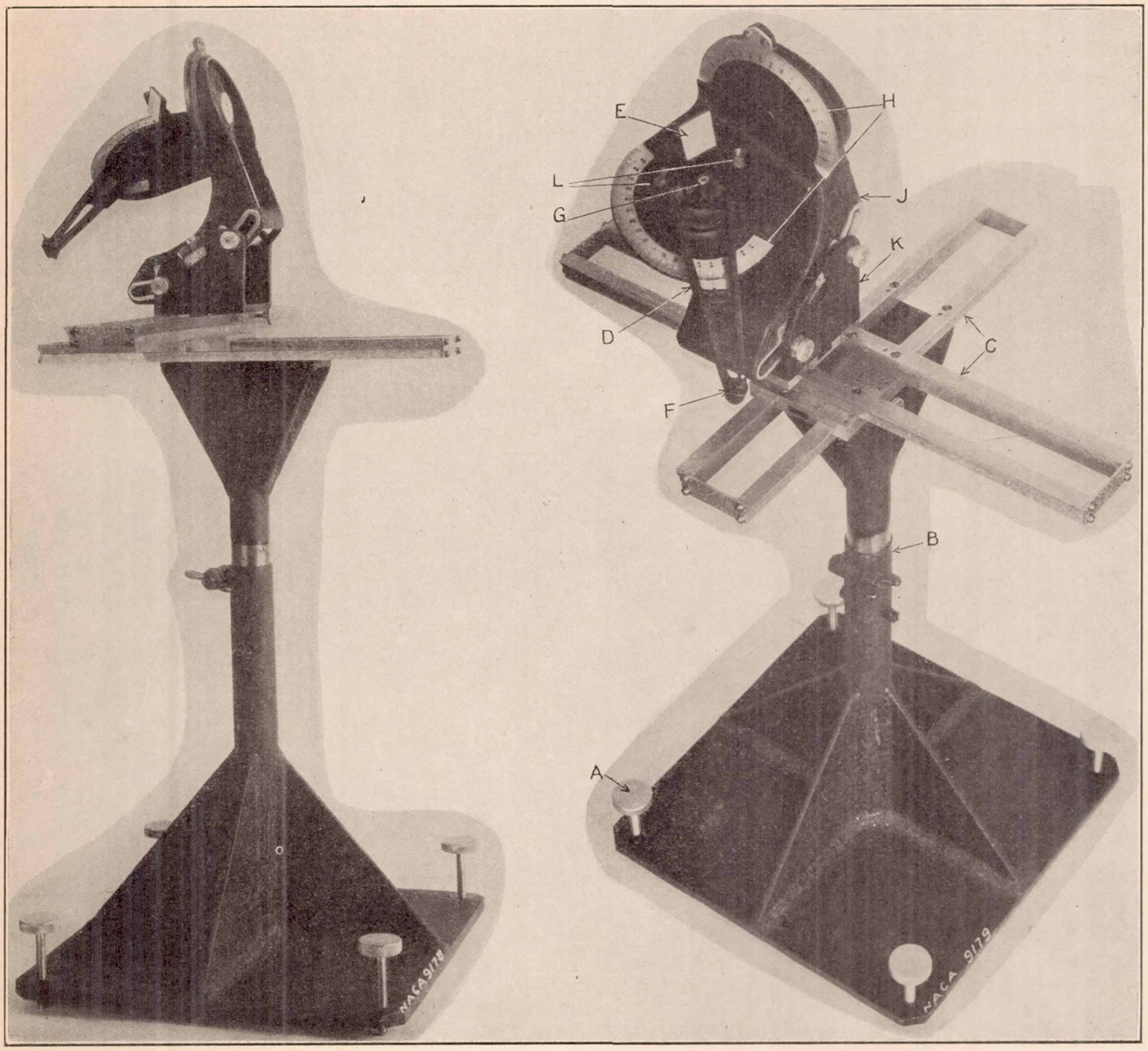


FIGURE 4.—N. A. C. A. visiometer.

The planes in which the angles defining a point in space are measured depend upon the type of chart to be used in representing them. As polar coordinates seemed best, for reasons to be given later, an instrument termed a "visiometer" was designed to measure them.

Photographs of the visiometer are reproduced as figure 4. All measurements being made with the airplane on the ground, the steel base of the instrument was designed to fit in the average seat. Adjusting screws A are provided for leveling. Vertical adjustment B and fore-and-aft and lateral tracks C permit the duralumin head to be placed at the desired center of the projection. The pointer D, which is sighted by means of the universally mounted mirror E, is equipped with a front bead sight F and a rear ring and cross-hair sight G. The intersection of the cross hairs is the point about which all motions of the instrument head are made. The pointer is mounted on the protractors H and the protractor mounting J. The protractor mounting may be rotated about the rear sight G in the bed K. The line of sight of the pointer is defined by the angles read on the protractors H. Level bubbles L are provided for setting up the instrument. The entire instrument weighs 27 pounds and occupies about the same space as would be taken by the pilot.

The procedure used in taking measurements with the instrument in an airplane is quite simple. The locator, shown with visiometer in figure 5, is placed with its tip at the point to be used as the center of the projection. The visiometer is then placed in the center of the seat, the cross hairs of the rear sight are placed at the tip of the locator and, by means of the adjustments available, the protractor is so set that its axes of rotation are perpendicular and parallel to the span and the thrust line of the airplane, the angle of the thrust line to the horizontal having been previously determined by a propeller protractor. This condition, in which the axis of rotation of the forward hemisphere is parallel to the thrust line of the airplane, the visiometer correctly located with respect to the seat, and the seat lowered so that the pilot is just fully protected by the windshield, is known as the "flight" attitude. The "landing" attitude is obtained by raising the seat through its full range of travel and pitching the protractor mounting so that the axis of the hemisphere is

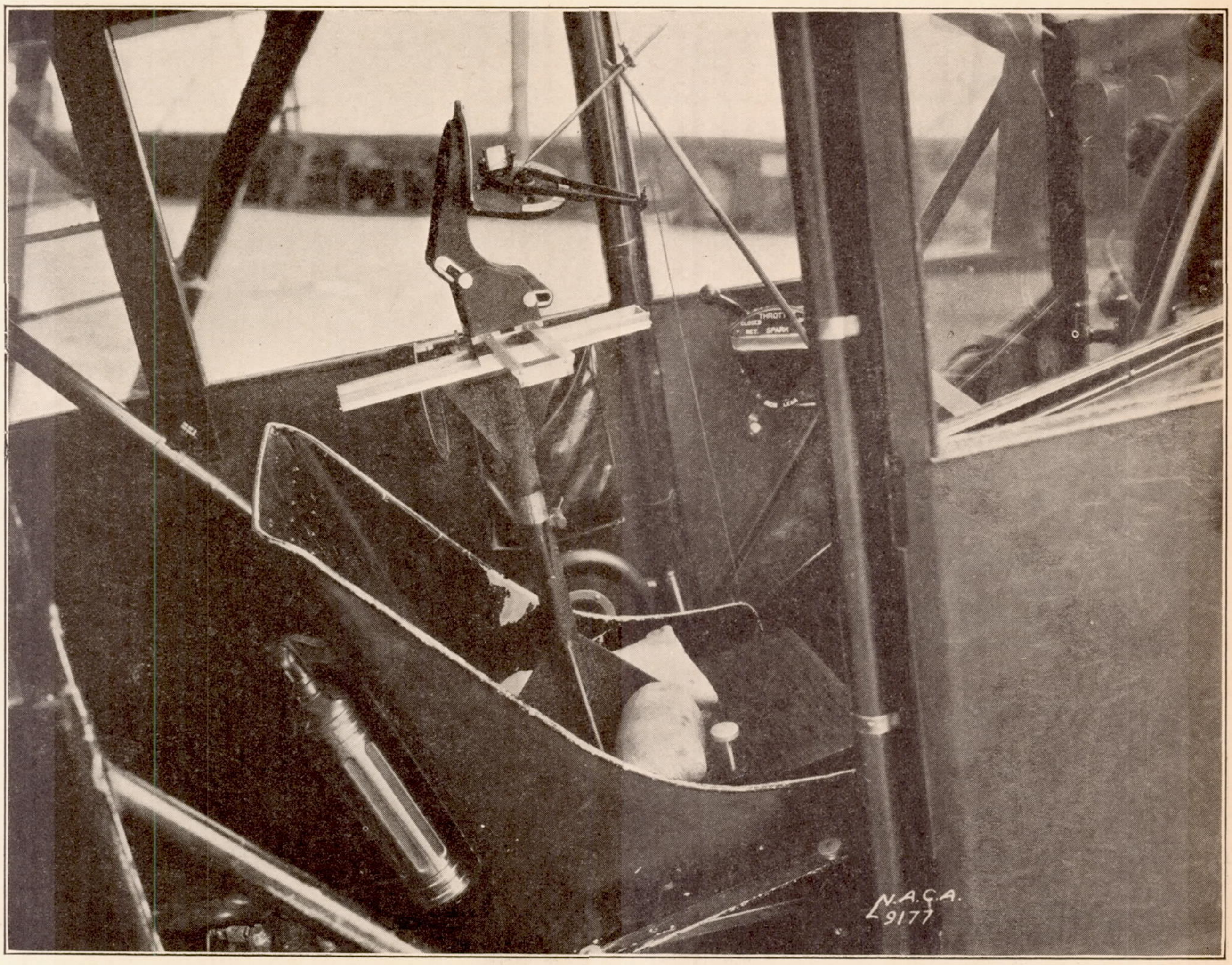


FIGURE 5.—N. A. C. A. visiometer and locator mounted in the cockpit of a Fairchild cabin monoplane.

below the thrust line of the airplane by an angle equal to the landing angle. In both the flight and landing attitudes the protractor mounting may be moved to the side positions. The outline of the structure of the airplane is measured with the center of rotation in each of the four positions: (1) Pilot central, flight attitude;

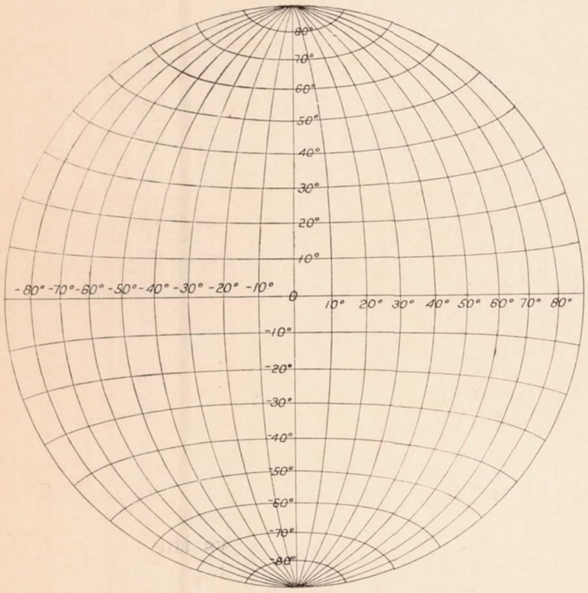


FIGURE 6.—Meridianal, or equatorial, projection of a hemisphere.

(2) pilot to side, flight attitude; (3) pilot central, landing attitude; and (4) pilot to side, landing attitude.

When making the measurements the instrument is sighted on various points defining the outline of the airplane and the data are plotted directly on a chart.

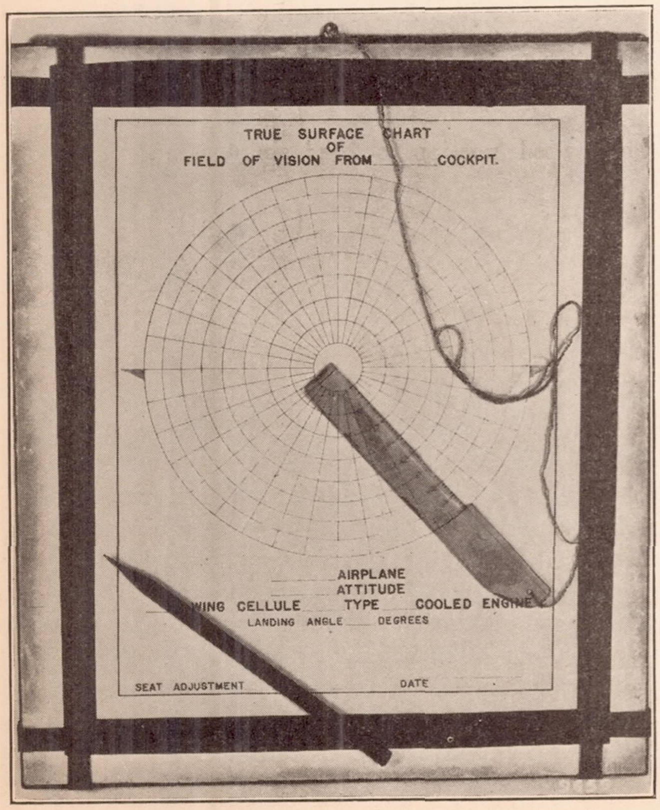


FIGURE 7.—Polar projection field-of-view chart, scale, and chart board.

Fair curves are drawn through the points obtained. It is less confusing if one part, such as the wing or windshield, is followed around to completion. Where the pilot's cockpit is located in the plane of symmetry of the airplane only the left portion of the hemisphere is measured unless some appreciable unsymmetrical

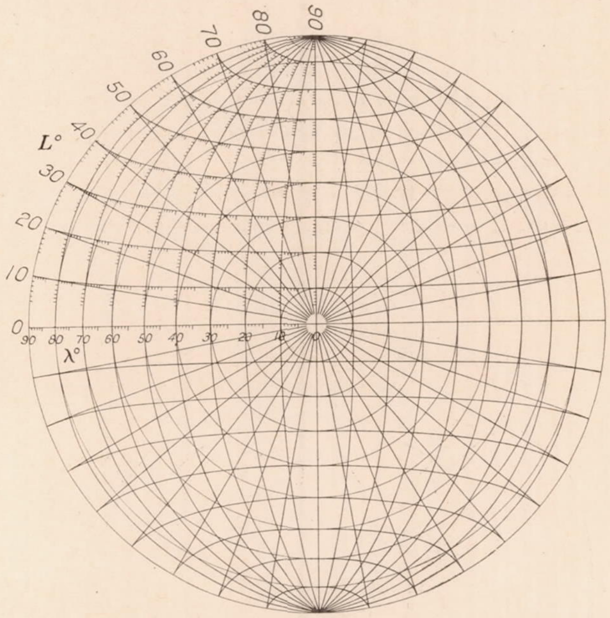


FIGURE 8.—Superposition of polar and meridianal projections of a hemisphere.

obstruction exists. After the angular measurements are made, the distances from the center of the projection to various points on the airplane are measured to be used in applying the binocularity correction.

It is desirable that the measurements be made in a well-lighted hangar with walls contrasting in color to that of the airplane. The airplane should be so placed that it is laterally level. The mounting and locating of the instrument requires approximately 45 minutes. Measurements from the four positions, including recording of the results, requires two men from 3 to 6 hours depending upon the complexity of the outline to be measured.

REPRESENTATION OF RESULTS

The representation of the surface of a sphere upon a plane has long been used in map making and no one method of projection has been found to be entirely satisfactory. (See references 13 and 14.) No map on a plane surface can accurately represent both size and shape of a figure on a spherical surface, for it is impossible to preserve the same scale in all directions at all points. Such a representation may be a compromise fulfilling one of the following conditions:

(1) It may keep the area directly comparable all over the map at the expense of the correct shape.

(2) It may keep the shapes of small features correct at the expense of a changing scale all over the map with the knowledge that large areas will not preserve their shape.

(3) It may be a compromise between (1) and (2) so as to minimize the errors by taking both shape and area into account.

(4) It may preserve the correct directions of all lines drawn from the center of the map.

Conditions (1) and (4) seemed most desirable for the representation of the field of view because of the possibility of measuring and comparing areas in an effort to establish a criterion. These two characteristics are maintained in a projection known as the "Lambert equal-area projection", a description of which will now be given.

It is necessary to have some points or lines of reference on the surface of a sphere so that other points

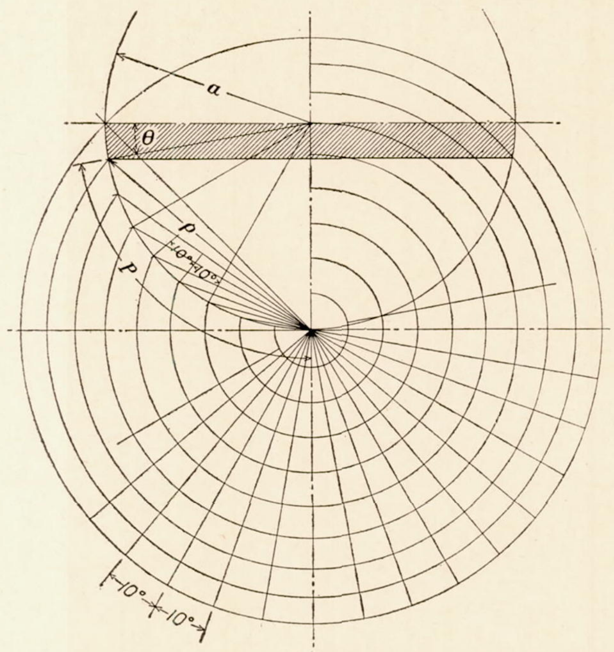


FIGURE 9.—Construction of Lambert equal-area polar projection.

may be located with respect to them. The most convenient method seems to be by lines representing latitude and longitude as used for points on the surface of the earth. The intersections of the axis of the sphere with the surface are the poles. The intersection with the surface of the sphere of a plane passed through the center of the sphere perpendicular to the axis is the equator. All planes containing the axis of the sphere intersect the surface to form meridians of longitude. Planes passed through the sphere parallel to the equator intersect the surface as parallels of latitude.

It is immediately apparent that a map of the projection of such a hemisphere may be made either with one pole as the center of the chart or with the center on the equator, in which case we have a projection on the meridian. The latter method will not be considered because of the inconvenience of computing the coordinates and the plotting of the double system of complex curves of the meridians and parallels; the intersection of these systems at oblique angles; and the consequent inconvenience of plotting positions. (See fig. 6.) A polar projection is more easily constructed because the meridians become straight lines and the parallels become concentric circles. (See fig. 7.) A superposition of these two forms of coordinates (fig. 8) is of value in applying the correction for binocularity.

In order to construct a chart of the Lambert equal-area polar projection, the radius of the circle representing the parallel on the projection is taken as the chord distance of the parallel from the pole on the sphere. Figure 9, in which circles are drawn for every 10° parallel on the sphere, shows the construction of such a chart for a sphere of radius a. The meridians are straight lines radiating from the pole and dividing the circles into equal parts. From this figure it is apparent that

$$\frac{\rho}{2a}=\sin\frac{P}{2} \text{ and } \rho=2a\sin\frac{P}{2}$$

where ρ is the chord distance of the parallel from the pole.

a, the radius of the sphere.

P, the arc from the pole to the parallel.

The area contained in the circle having radius ρ is $\pi\rho^2$ and equals $4\pi a^2 \sin^2 \frac{P}{2}$.

It remains but to prove that the area of the spherical surface, or polar cap, bounded by the same parallel is equal to that just found on the chart. The surface area of the hemisphere is $\frac{4\pi a^2}{2}$ or $2\pi a^2$. The area of the shaded portion is $2\pi a^2 \sin \theta$. This expression becomes $2\pi a^2 \cos P$ since $\theta=\left(\frac{\pi}{2}-P\right)$.

$$\text{Area of cap}=2\pi a^2-2\pi a^2 \cos P=2\pi a^2 (1-\cos P)$$

$$=4\pi a^2 \sin^2 \frac{P}{2} \text{ which is equal to the plane}$$

area found above. Thus the total area of the polar cap is equal to the total area of the chart. Since the proof holds for any parallel, the area of the ring between any two parallels is equal in area to the area on the chart and, since the ring is equally divided by the meridians, the area of a section on the chart is equal to the area on a sphere bounded by the same parallels of latitude and meridians of longitude. The equal-area projection therefore preserves the ratio of areas constant; that is, any given part of the chart bears the same relation to the area that it represents that the whole chart bears to the whole area represented.

A form, including the chart just described, was constructed and prints were made from it to record directly the data obtained by the visiometer. In figure 7 one is shown mounted on a data board, with the celluloid scale used to facilitate plotting.

The projection as made from a single point is first drawn on the chart in dotted lines to assist in interpreting the chart. The binocularity correction obtained from figure 10 is then applied by the use of figure 8 and the resultant figure drawn in solid lines. The blind regions are cross-hatched and transparent surfaces properly represented in the final chart. In addition to plotting the outline, photographs of the airplane and the general information necessary to fill in the complete form were obtained.

the correction, it is therefore necessary to convert the magnitude of the correction into terms of the scale of the chart in the region in which the correction is to be applied. This conversion is accomplished by means of figure 10. When the distance of a point on the obstruction from the pilot and the horizontal plane or latitude in which it occurs are known, the magnitude of the correction to be applied to the chart may be determined directly in terms of latitude and longitude difference to the new position in which binocularity locates it.

It will be noted that the value of the correction increases very rapidly with decreasing distance from the instrument, particularly below 10 inches, but fortunately portions of the structure are seldom very close to the pilot's face.

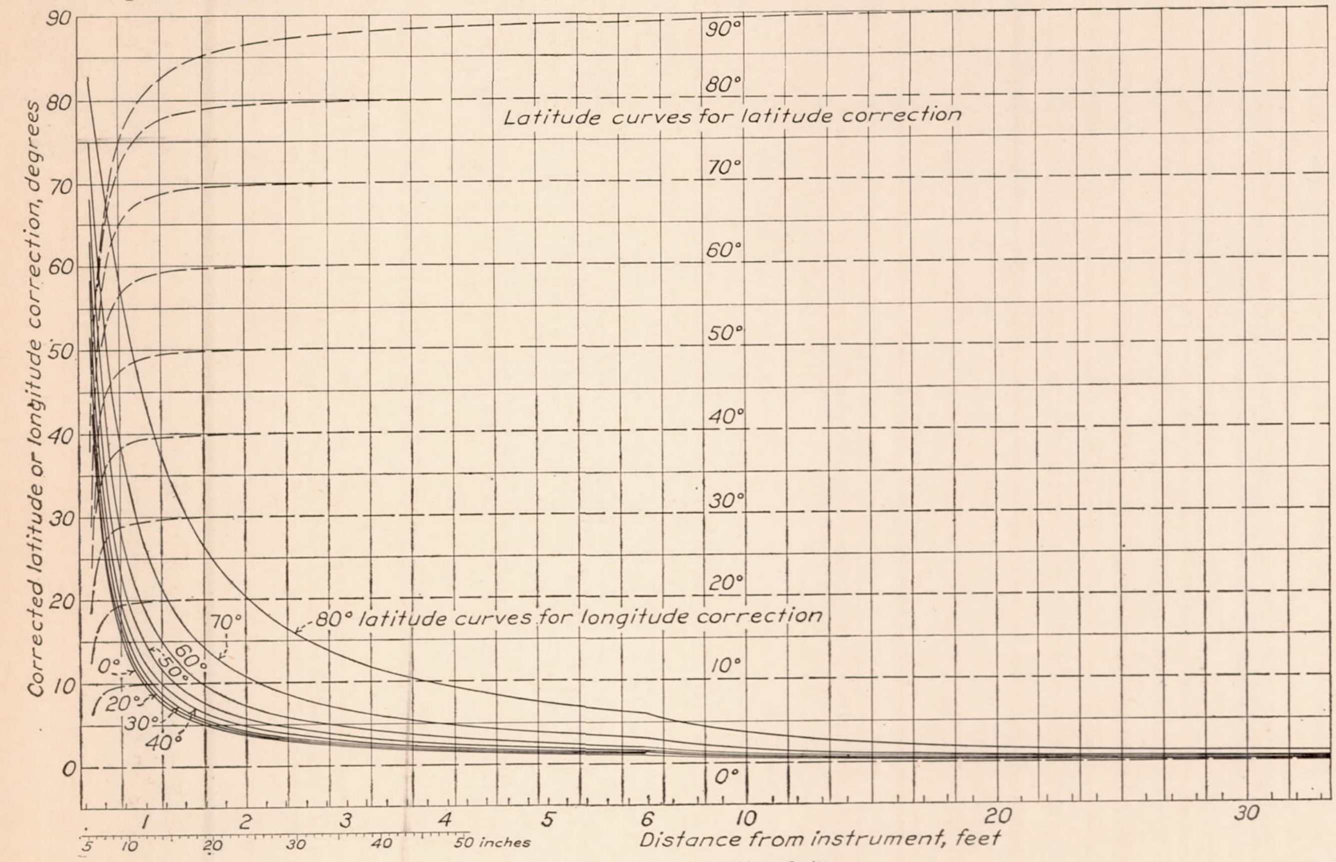


FIGURE 10.—Correction for binocularity.

The application of the binocularity correction to the measured data requires some explanation. In the preliminary considerations the correction was shown to be applicable for the reduction of obstructions in planes containing the eyes and to vary with the distance from the various parts of the airplane to the pilot. By a superposition of the meridianal projection on the polar projection (fig. 8), the location of the horizontal planes and the scale of the chart along them is determined. Since the meridians converge toward the poles, the scale on the parallels is reduced in that direction. The correction, however, is a portion of a great circle and has a certain magnitude α regardless of its point of application on the chart. In order to apply

Owing to the variations in the paper used, slight variations in the size of the chart have been found. As area evaluation will most probably be made on a percentage basis, the results should not be appreciably affected. From a large number of charts it was determined that the maximum variation in radius was ± 1 percent and that the area of the form was correct to within ± 1 percent. When plotting on the chart, an accuracy of $\frac{1}{4}°$ may be maintained in a radial direction and between radial lines on the periphery. This latter error increases toward the center of the chart owing to the convergence of the radial lines, although the importance of this accuracy decreases.

DISCUSSION

The visiometer has proved very practicable. It is convenient to transport, easy to set up, and simple to operate. The mirror facilitates sighting with little motion on the part of the observer. Depending upon the size of the airplane, the location of the cockpit, the entering steps, the wings, and the type of cockpit enclosure if one exists, it has frequently been found inconvenient and, in many cases, very uncomfortable to reach the instrument to operate it after it has been mounted in the cockpit.

The variety of locations of regions that obstruct the pilot's vision in the forward hemisphere is shown by the charts for airplanes representing different cockpit and wing arrangements. Some difficulty may be experienced in interpreting the charts owing to shape distortions near the edge. It is only necessary to remember that the chart is the representation of a hemisphere on a plane surface and that it extends through 90° in every direction from the center.

The entire horizon is visible in the F11C–2 (fig. 11) airplane in the flight attitude. The seat being lowered, the pilot is well protected by the windshield in the central position, while still able to get from behind it by a small movement of the head to the side. The region restricted by the engine and wings is not materially reduced by lateral movement, although that restricted by the fuselage is improved. The several small blind regions caused by the cabane and interplane struts are of small consequence, particulary the former, as they are considerably displaced by lateral movement. In the landing attitude the nose of the

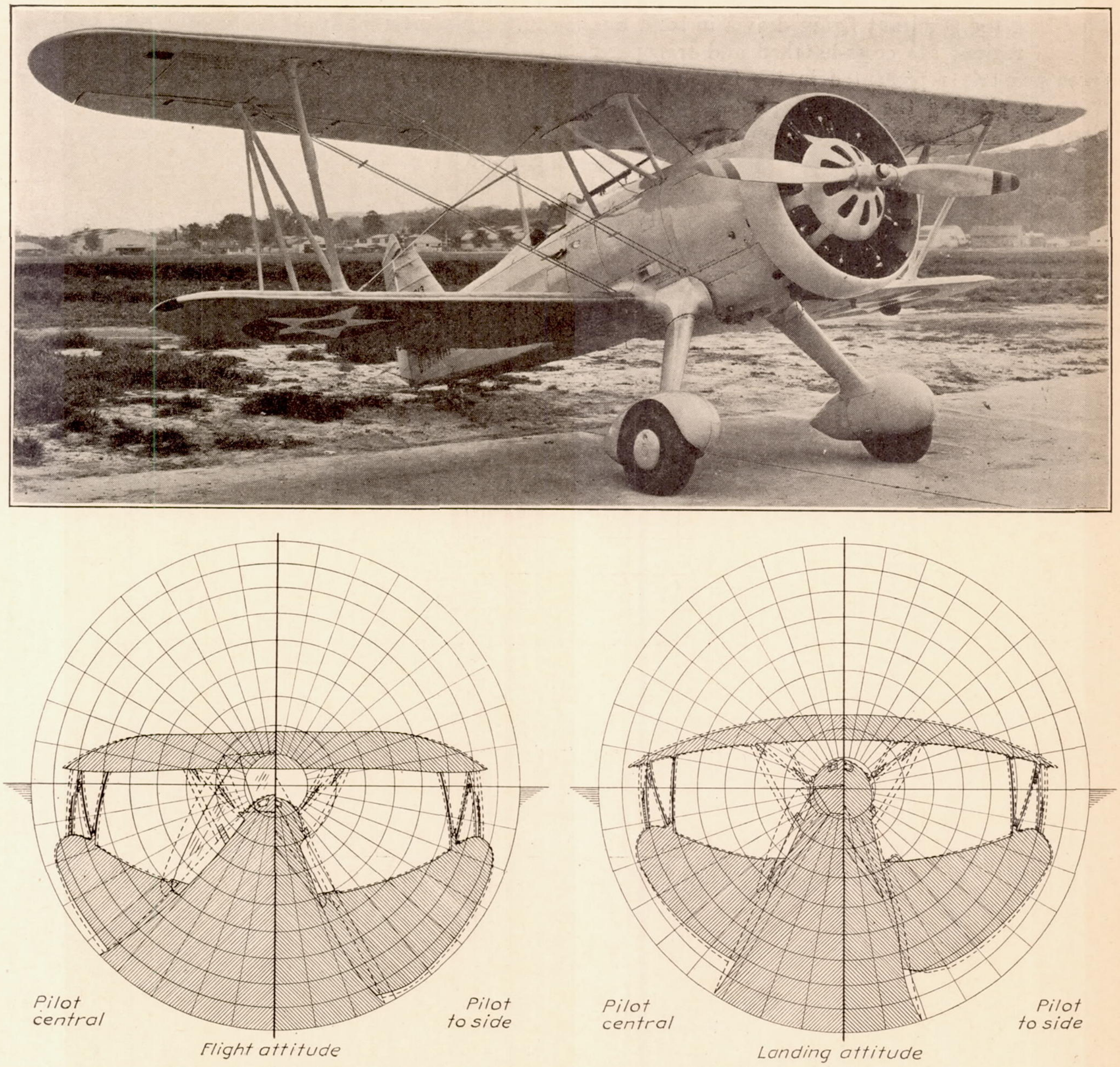


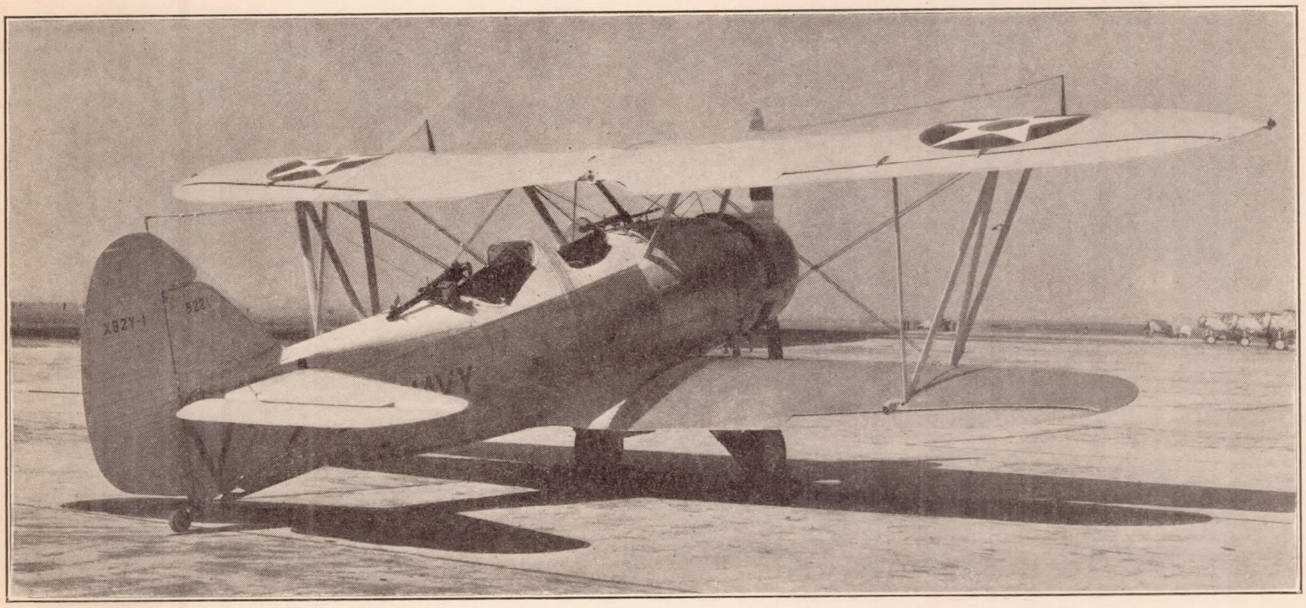
FIGURE 11.—Photograph and field-of-view charts for tractor biplane fighter F11C–2 with cockpit behind wing cellule.

fuselage and the engine entirely restrict the view in the direction of flight. By the raised seat the pilot is placed more nearly on the chord line of the wing, however, and the blind areas due to it are materially reduced. In both attitudes the gaps between the engine cylinders appear to be of appreciable magnitude.

Figure 12 shows that the top wing and the fuselage of the XB2Y–1 airplane cover considerable area and, improved by replacing the cabin top with transparent material.

The XSE–2 airplane (fig. 15), although having an engine in the nose of the fuselage, has no area restricted in the forward hemisphere by the wing.

In all the charts the effect of binocular vision in reducing the width in the horizontal plane of structural members, particularly those near the pilot, is quite



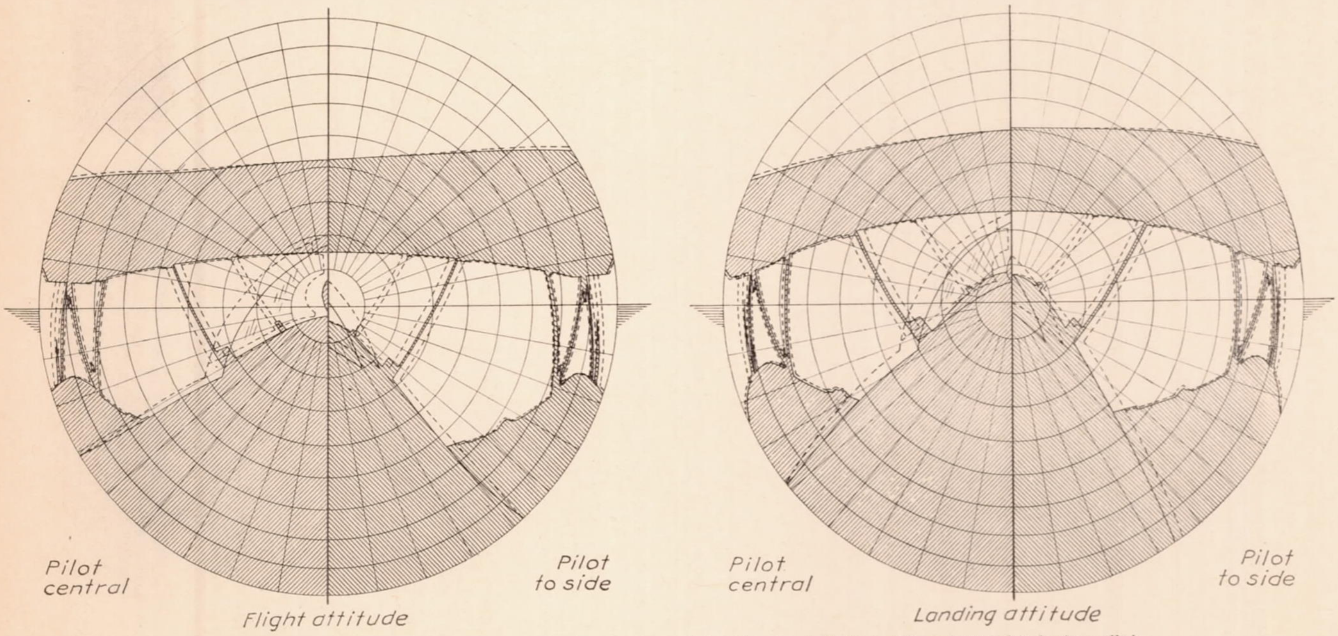


FIGURE 12.—Photograph and field-of-view charts for tractor biplane bomber XB2Y–1 with cockpit behind wing cellule.

since the engine is completely cowled, no view between the cylinders is obtained. The P–26A low-wing monoplane (fig. 13) is notable for the unrestricted view in the upper portion of the hemisphere, the absence of struts, and the large area covered by the engine.

In figure 14 showing the W–1 airplane, the excellent view obtained with a pusher arrangement is shown. This particular arrangement could be considerably apparent. Equally so is the consistent location of the region blanked by the fuselage. The small portions of the horizon restricted by the nose of the fuselage in the landing attitudes for the W–1 and XSE–2 airplanes are particularly noteworthy.

Of course, there are many other positions which the pilot may assume in addition to those which have been chosen as representative. The pilot may sway fore

and aft and also effect a movement of his head in a vertical direction, in addition to moving his eyes. The view afforded by these movements may be of interest in particular cases and may be determined and charted in a manner similar to that described. It may be argued, however, that the airplane of the future should be so arranged as to afford the pilot obtained for the four described positions of the pilot may be combined into one chart for more direct comparison, and may even include data from other and more extreme positions. For the sake of descriptive simplicity, these variations have been omitted in the charts herein presented, although it may be of value when the subject of evaluation is given more attention.

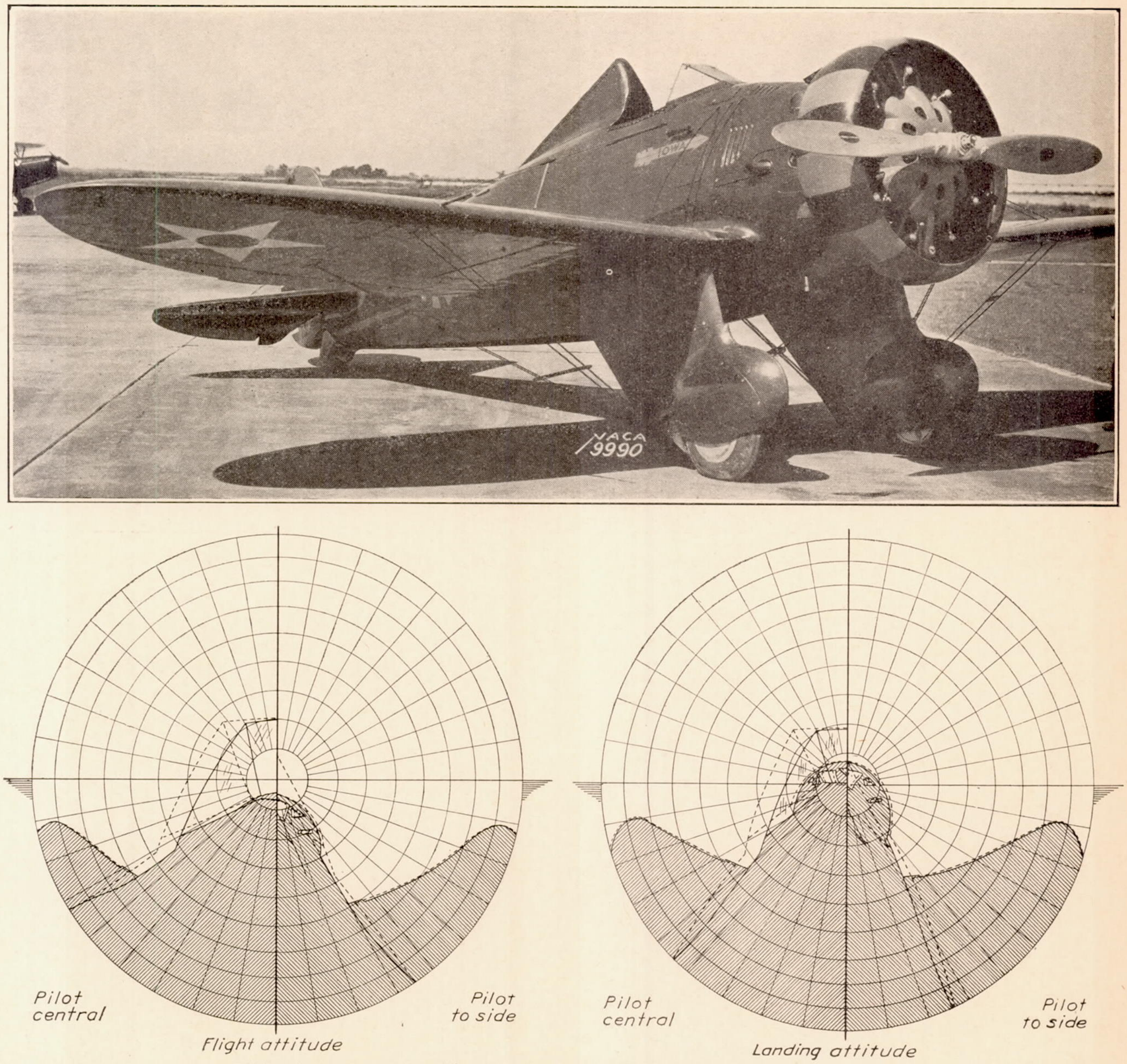


FIGURE 13.—Photograph and field-of-view charts for tractor low-wing monoplane fighter P–26A.

maximum desirable view with no inconvenience or unnecessary movement on his part. It would therefore appear that in measuring the view from existing airplanes the aim should be to determine what can be seen from such positions and thus what improvement should be effected, rather than what can be seen from unusual and uncomfortable positions that the pilot may assume.

The presentation of the final data on the charts may also be varied in many ways. For example, the charts

CONCLUDING REMARKS

It is believed that the method described reasonably represents the view obtained by the pilot and permits more rational comparisons of the relative merits of various airplane arrangements than has been possible heretofore. The method may be extended to include the rear hemisphere or may be used at any other observation point. The method is adaptable for use in rating fields of gunfire as well as the field of view of photographers and observers.

In any event, the plotting of the view in the forward hemisphere from existing airplanes, together with the opinions received from the operating personnel, should result in a more definite understanding of field-of-view requirements and thus be a contribution to improved safety in flight.

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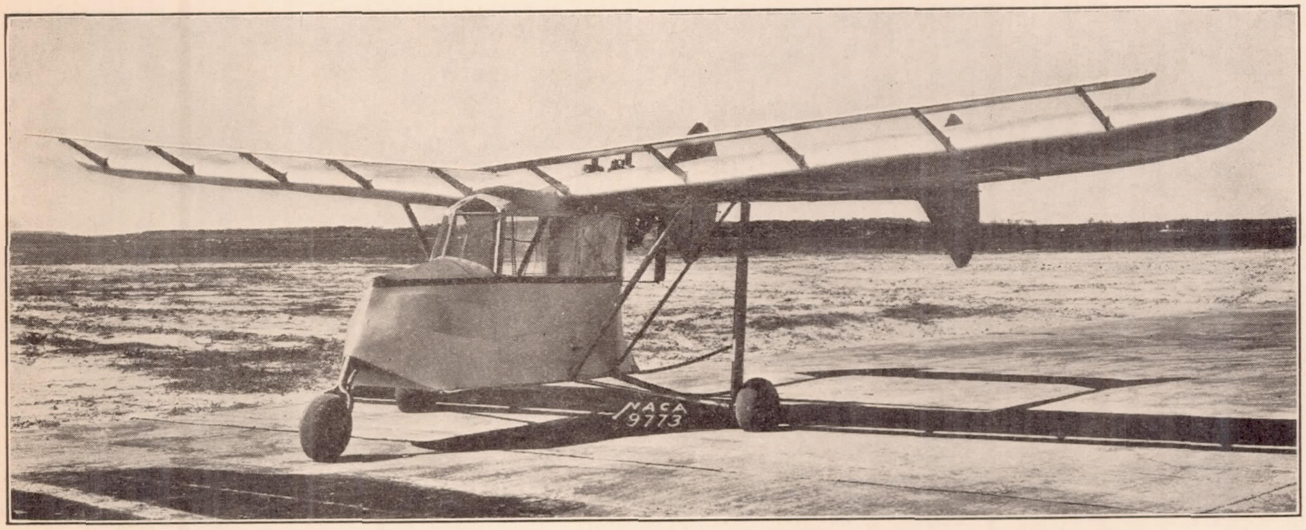

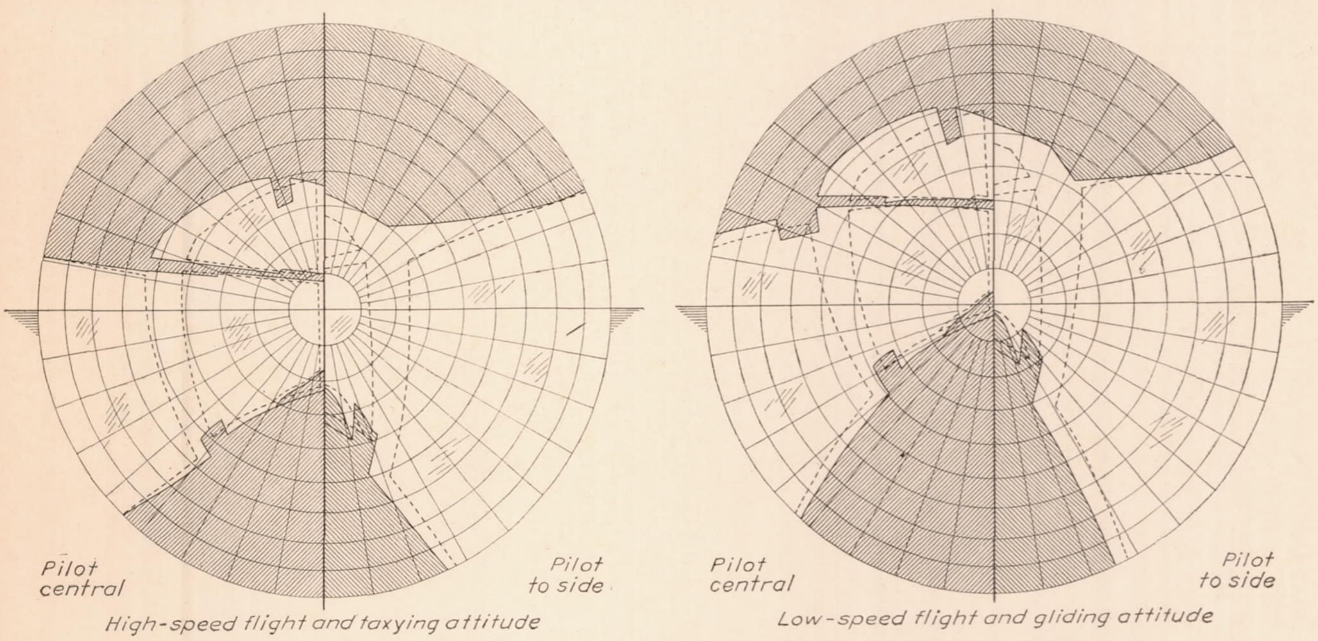

FIGURE 14.—Photograph and field-of-view charts for pusher high-wing monoplane W-1 with cockpit ahead of wing.

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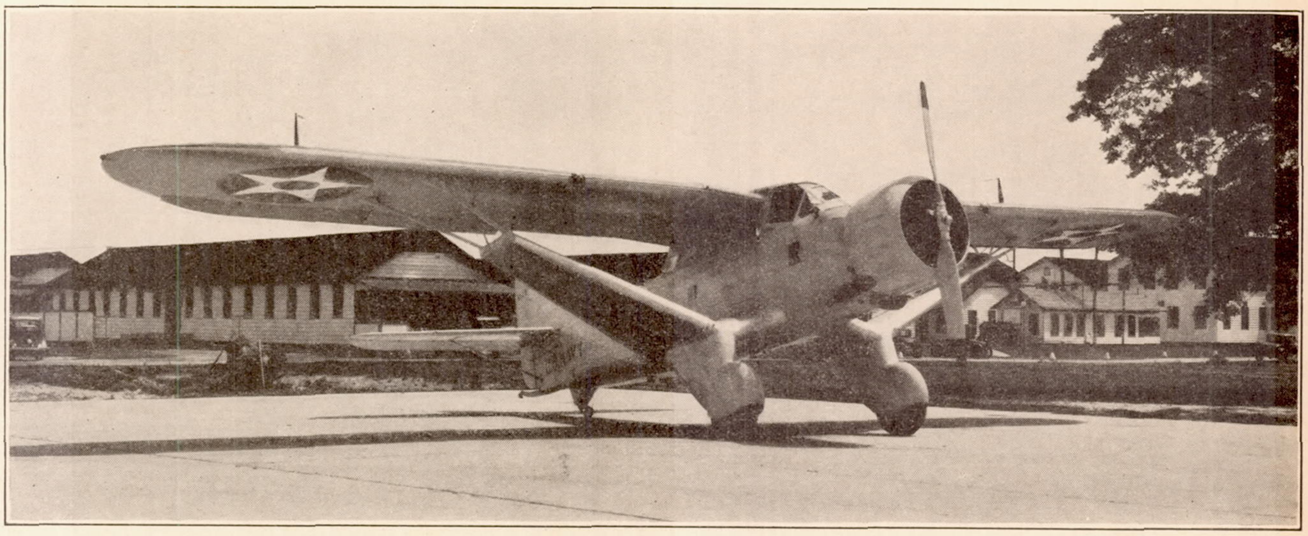

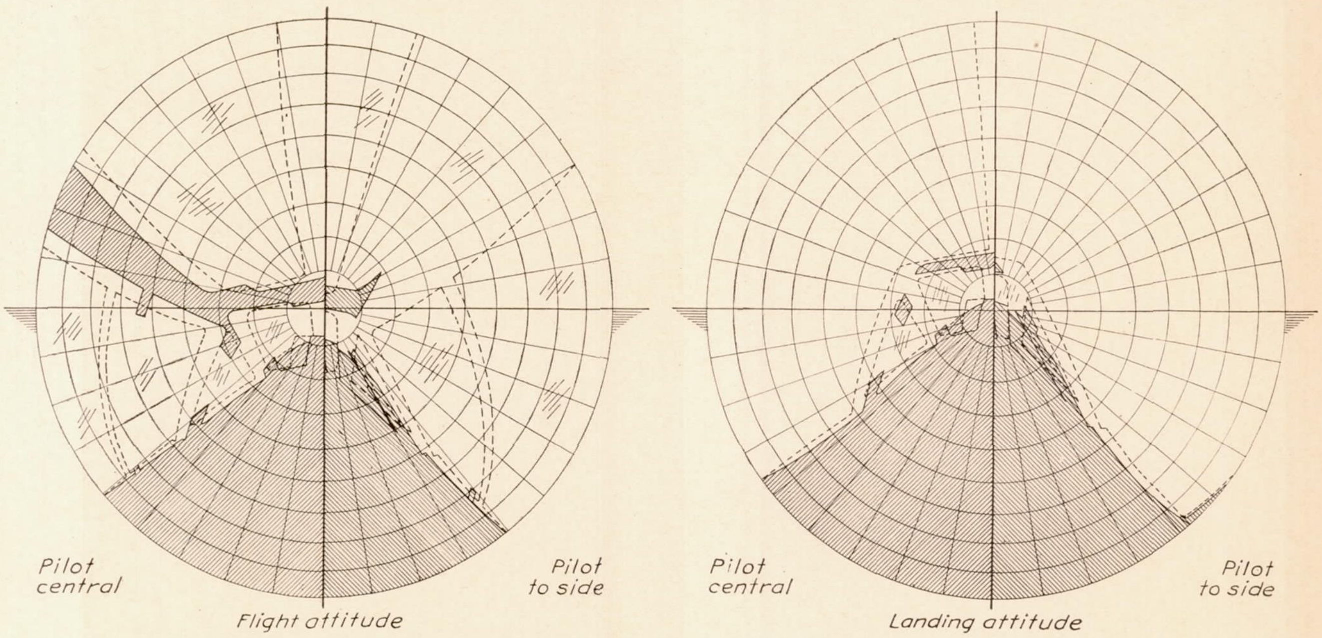

FIGURE 15.—Photograph and field-of-view charts for tractor high-wing monoplane scout XSE-2 with cockpit ahead of wing.

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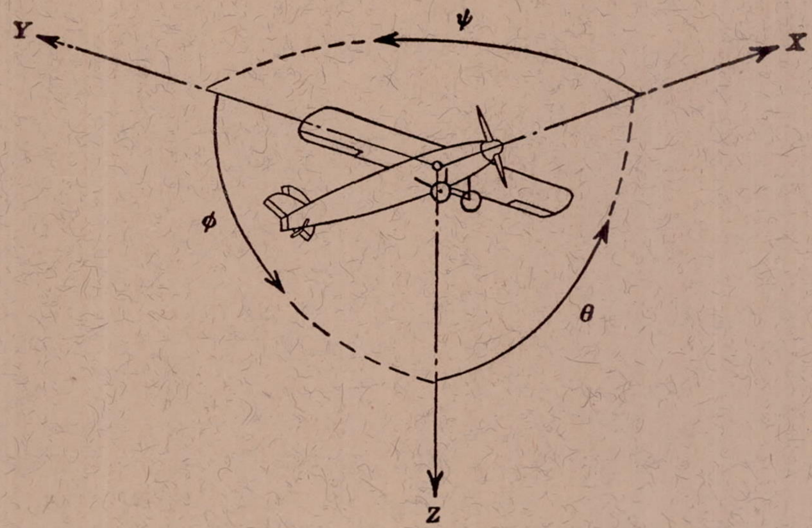

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	Rolling	L	$Y \longrightarrow Z$	Roll	ϕ	u	p
Lateral	Y	Y	Pitching	M	$Z \longrightarrow X$	Pitch	θ	v	q
Normal	Z	Z	Yawing	N	$X \longrightarrow Y$	Yaw	ψ	w	r

Absolute coefficients of moment

$C_l=\frac{L}{qbS}$ (rolling) $C_m=\frac{M}{qcS}$ (pitching) $C_n=\frac{N}{qbS}$ (yawing)

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter
p, Geometric pitch
p/D, Pitch ratio
V', Inflow velocity
V_s, Slipstream velocity
T, Thrust, absolute coefficient $C_T=\frac{T}{\rho n^2 D^4}$
Q, Torque, absolute coefficient $C_Q=\frac{Q}{\rho n^2 D^5}$

P, Power, absolute coefficient $C_P=\frac{P}{\rho n^3 D^5}$
C_s, Speed-power coefficient $=\sqrt[5]{\frac{\rho V^5}{P n^2}}$
η, Efficiency
n, Revolutions per second, r.p.s.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 hp. = 76.04 kg-m/s = 550 ft-lb./sec.
1 metric horsepower = 1.0132 hp.
1 m.p.h. = 0.4470 m.p.s.
1 m.p.s. = 2.2369 m.p.h.

1 lb. = 0.4536 kg.
1 kg = 2.2046 lb.
1 mi. = 1,609.35 m = 5,280 ft.
1 m = 3.2808 ft.